Kawasaki

Gas Turbines

National Turbine Technology And Regulatory Forum

5, 6 March 2003

San Diego, CA

Overview

- **Who Is Kawasaki Gas Turbines?**
- What Causes NOx?
- How Can We Control NOx?
- Field Results
- Summary

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Kawasaki Gas Turbine History

- 1943 Built First Aircraft Gas Turbine Engine
- 1950's Service Operations - US Military
- 1972 Started Development of Industrial Gas Turbines Engines
- 1974 First S1A-01 (200 kW) Gas Turbine Engine
- 1977 First Gas Turbine Generator Set Delivered
- 1979 First Mobile Gas Turbine Genset Delivered
- 1984 First Co-generation System Delivered
- 1988 First Cheng-cycle Co-generation System Delivered
- 1988 Developed M1A-13 Gas Turbine (High Efficiency) Engine
- 1993 Developed M7A-01 Gas Turbine (High Efficiency) Engine
- 1995 Developed M1A-13D with Dry Low NOx System
- 1997 Over 5,000 Gas Turbine Engines Delivered
- 1999 Ceramic Gas Turbine 302, World Record Efficiency 42.1%
- 2000 Introduced Catalytic Combustion - World's Cleanest Turbine
- 2001 Introduction Of L20A
- 2002 Over 7,000 Gas Turbine Engines Delivered

More To Come!!

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Kawasaki Aircraft Turbines

Risk Share Partner

Pratt & Whitney

GE

Rolls Royce

Etc

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Kawasaki Aircraft Turbines

Pratt & Whitney

- F100
  - F-15 Eagle
  - F-16 Falcon
- PW4000
  - Airbus A300/A310/A330
  - Boeing B747/767/777
- V2500
  - Airbus A319/A320/A321
  - MD-90

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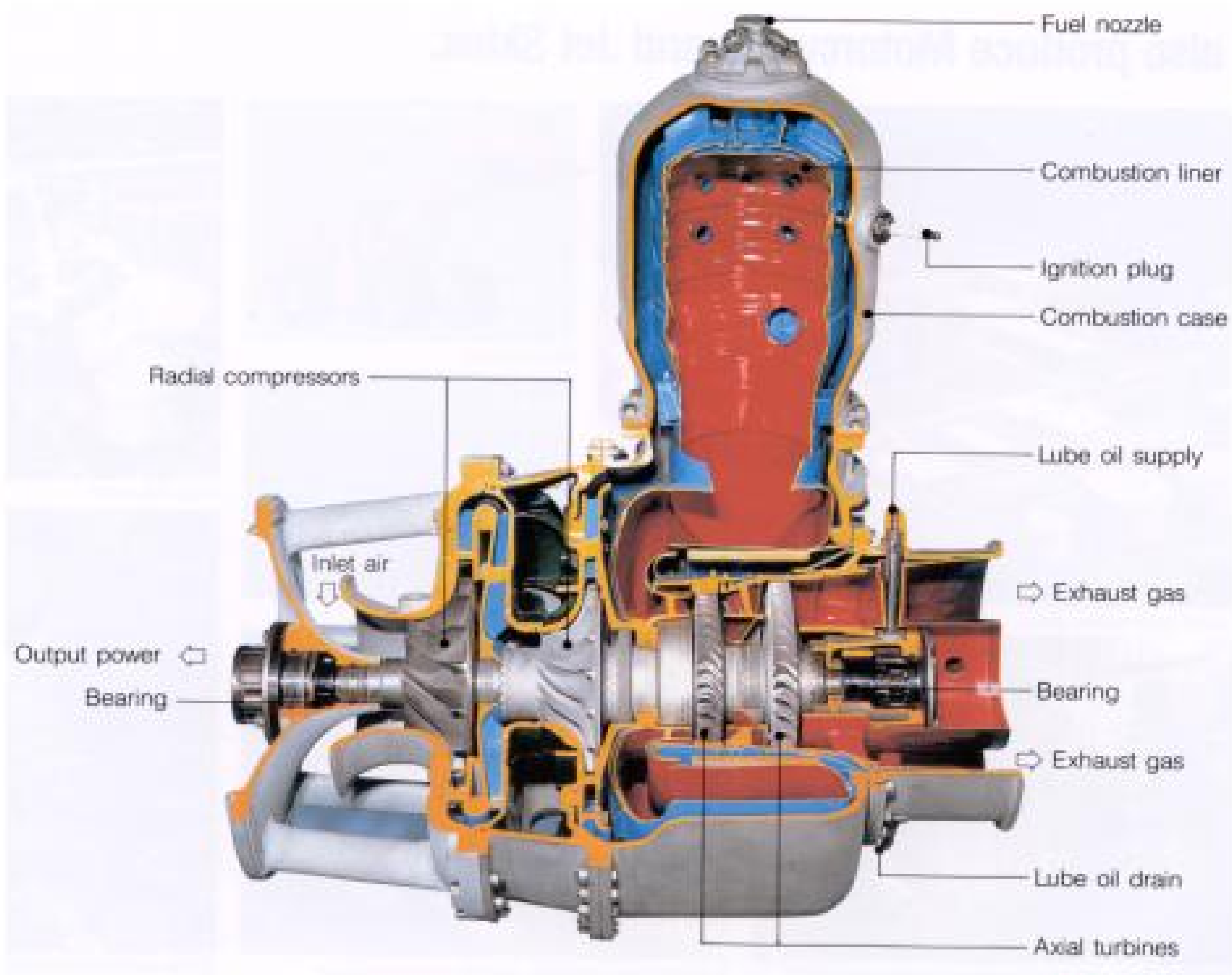
Kawasaki Industrial Turbines



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Kawasaki Industrial Turbines

• GPB07D	650 kWe
• GPB15D	1434 kWe
• GPB15X	1423 kWe
• GPB60D	5265 kWe
• GPB70D	6500 kWe
• GPB180D	17,000 kWe

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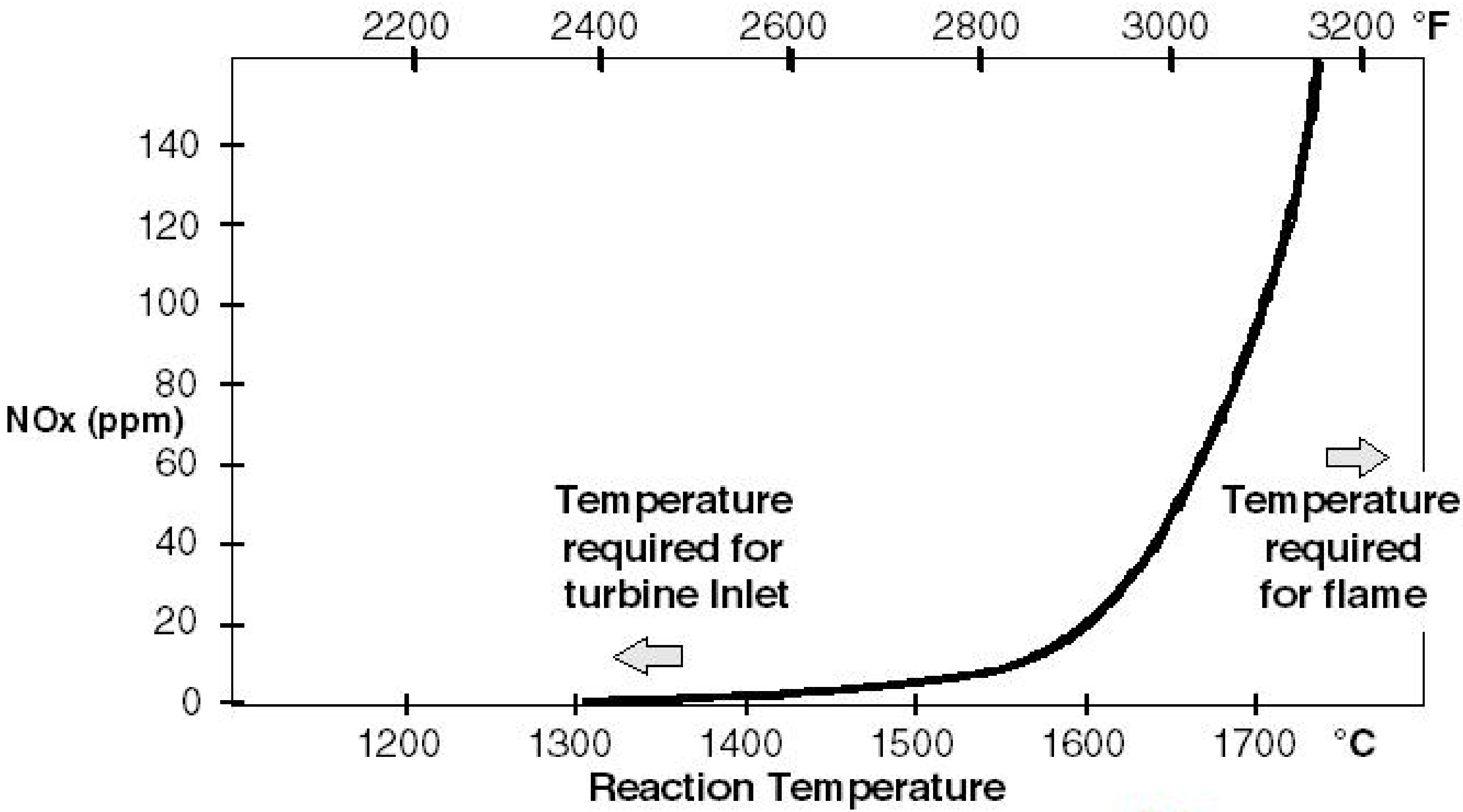
NOx Caused By High Temperatures



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Kawasaki's Combustion Technology

- Dry Low Emissions (DLE)
- Catalytic Combustors

Kawasaki's Combustion Technology

- Dry Low Emissions (DLE)
  - Current "State Of The Art"

Kawasaki's Combustion Technology

Dry Low Emissions (DLE) Design Concept

- Lean, Pre-mixed Combustion
- Multiple Fuel Nozzles
- Fuel Nozzle Staging

Kawasaki's Combustion Technology

DLE Combustor

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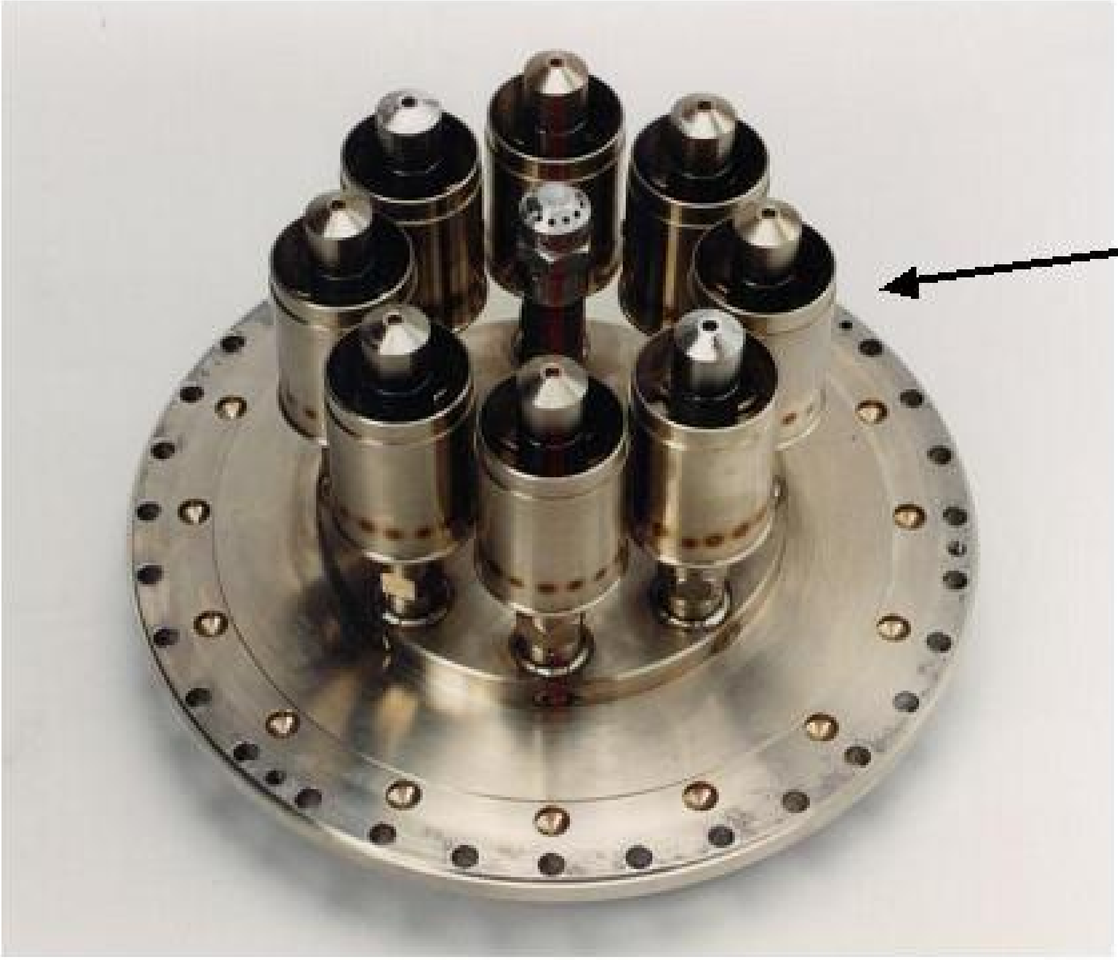
Kawasaki's Combustion Technology



DLE Burner
Assembly

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Kawasaki's Combustion Technology

- Guaranteed NOx Emissions With DLE
  - Less than 25ppm On Larger Machines
  - Less than 14ppm On Smaller Machine
- Low NOx power range - 85 to 100% load

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Kawasaki's Combustion Technology

- Catalytic Combustors

Kawasaki's Combustion Technology

- Catalytic Combustion
  - In Development Since 1982
  - ASME Paper Published 1987
  - Verified Module Durability 1999
  - Development Complete 2000
  - First Commercial Order 2000
  - Delivered First Commercial Units 2001
  - Demonstrated In Practice 2002

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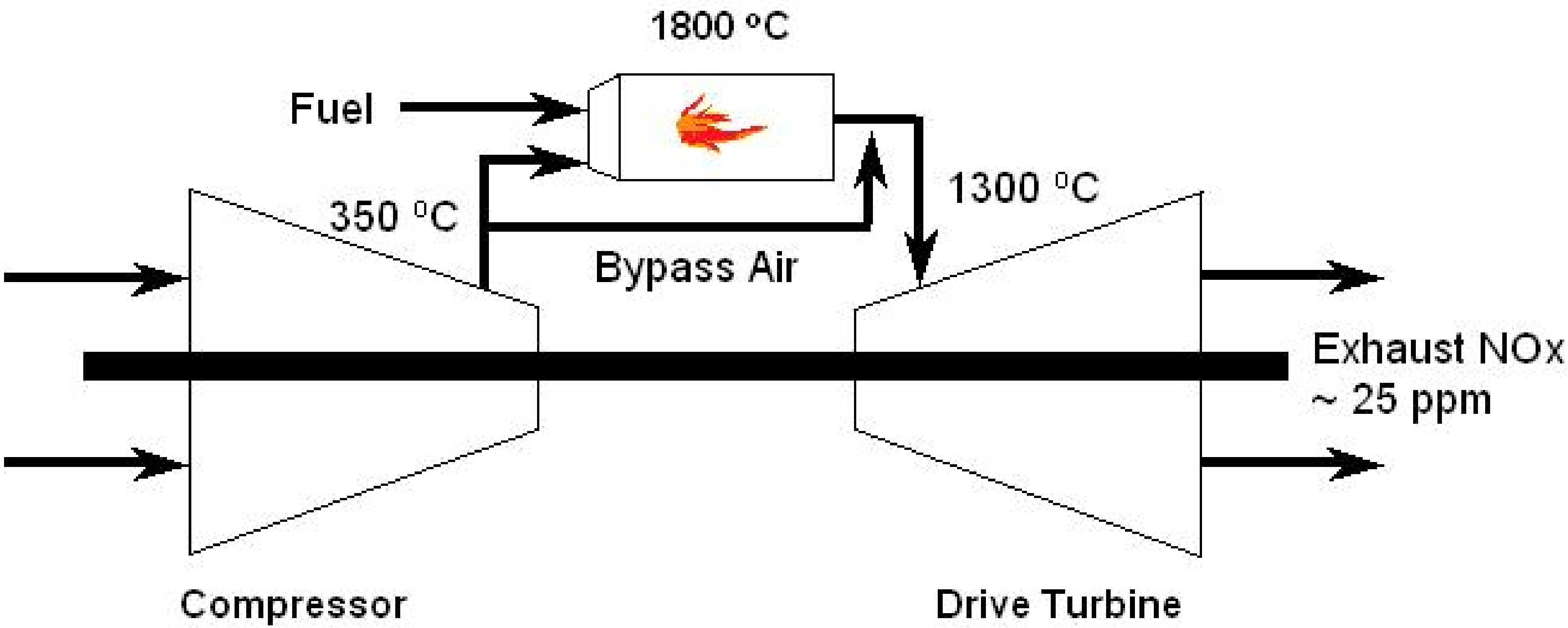
Flame Combustion System



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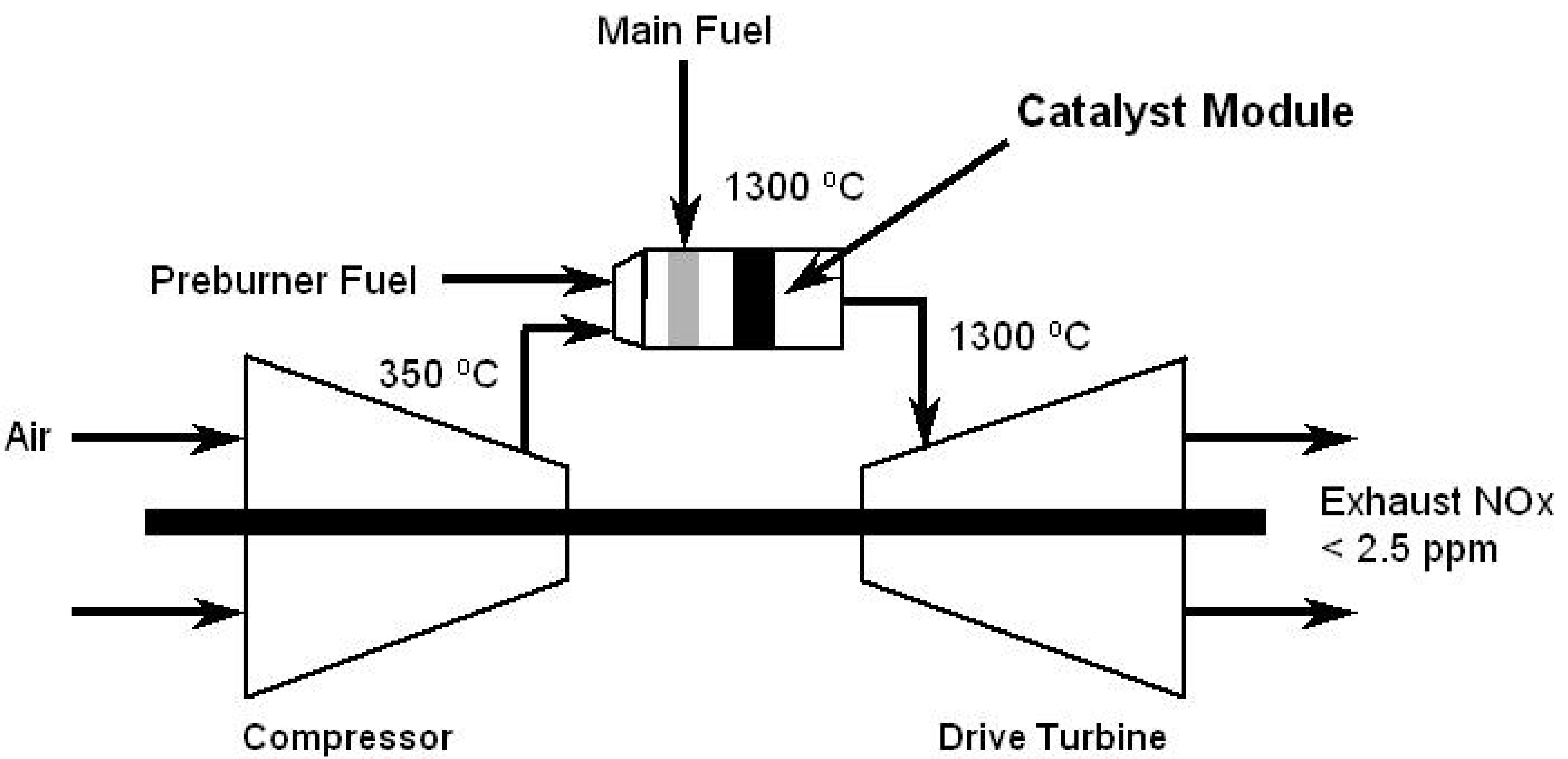
Catalytic Combustion System



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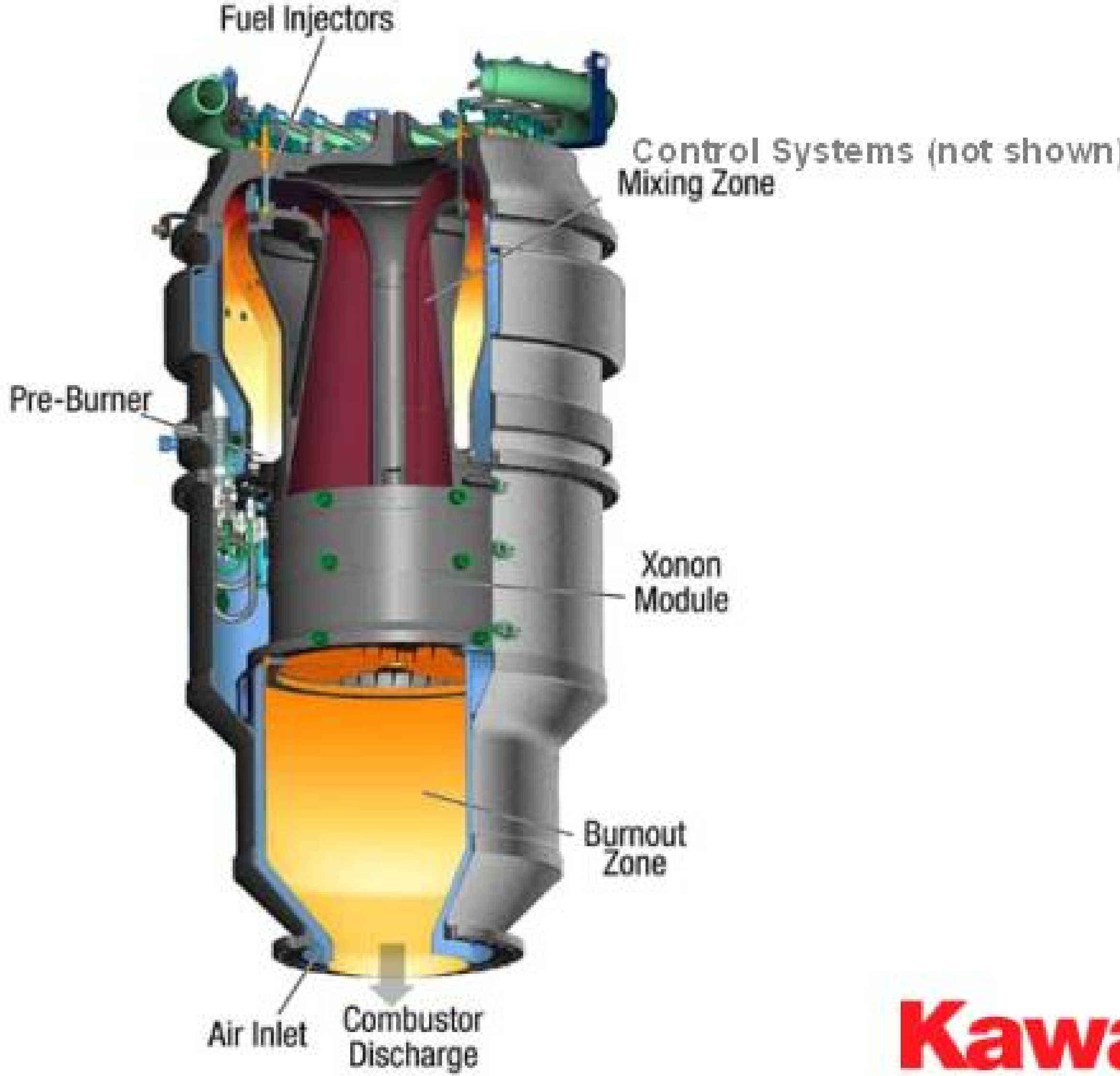
Catalytic Combustion System



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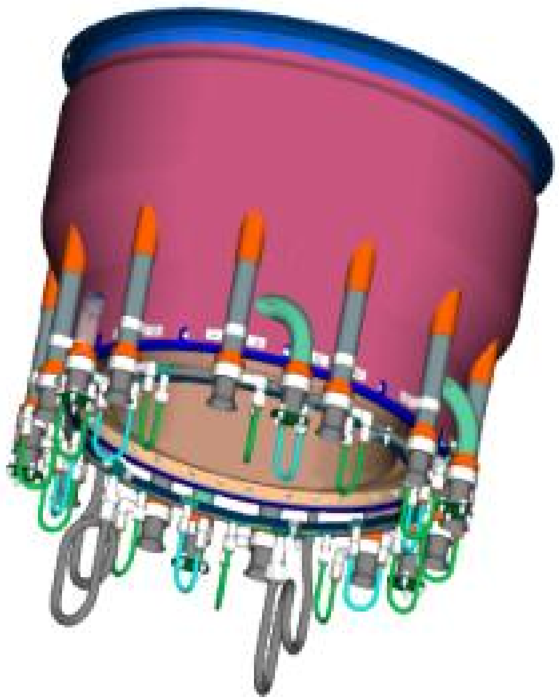
Catalytic Combustion System

Preburner Module

- Keeps catalyst in operating window
- Allows engine start-up
- Source of NOx



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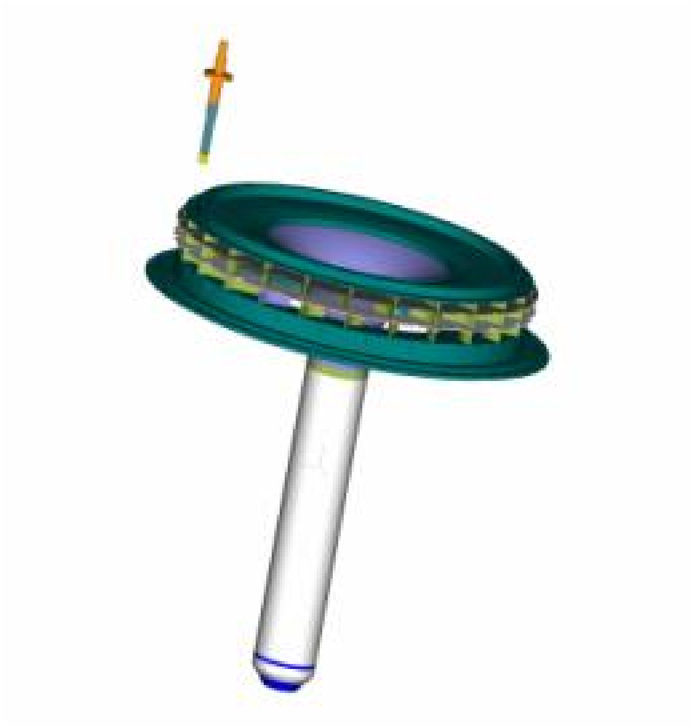
Catalytic Combustion System

Pre-mixer

- Improves catalyst fuel and air uniformity to prevent higher temperature regions in catalyst



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Catalytic Combustion System

Burn Out Zone

- Complete combustion of remaining fuel (homogenous combustion)
- Complete CO and UHC burnout

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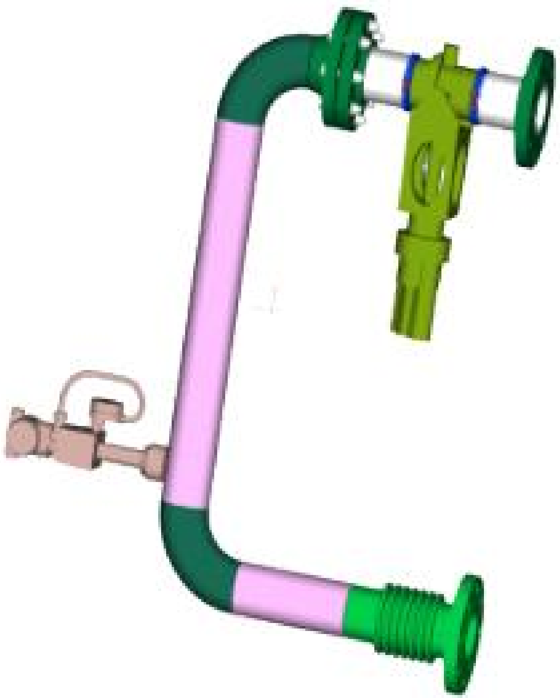
Catalytic Combustion System

Bypass System

- Increases load turndown capability
- Keeps catalyst in operating window



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Catalytic Combustion System

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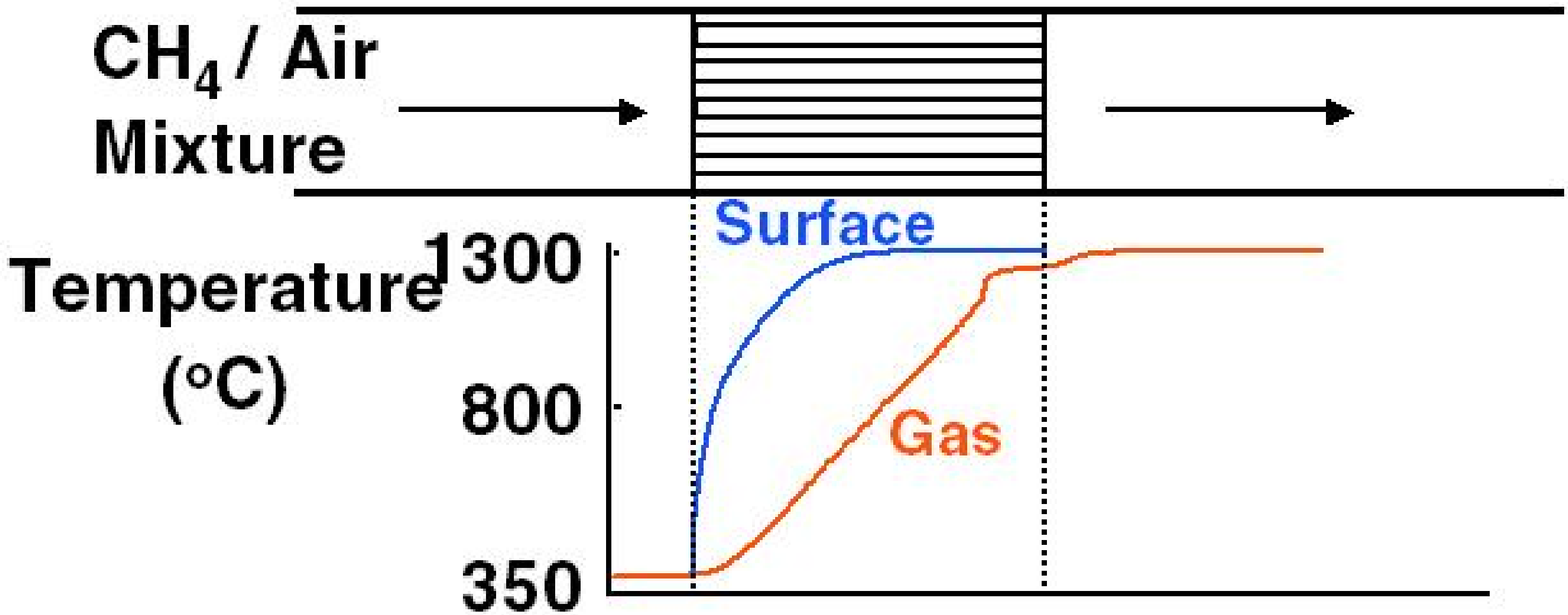
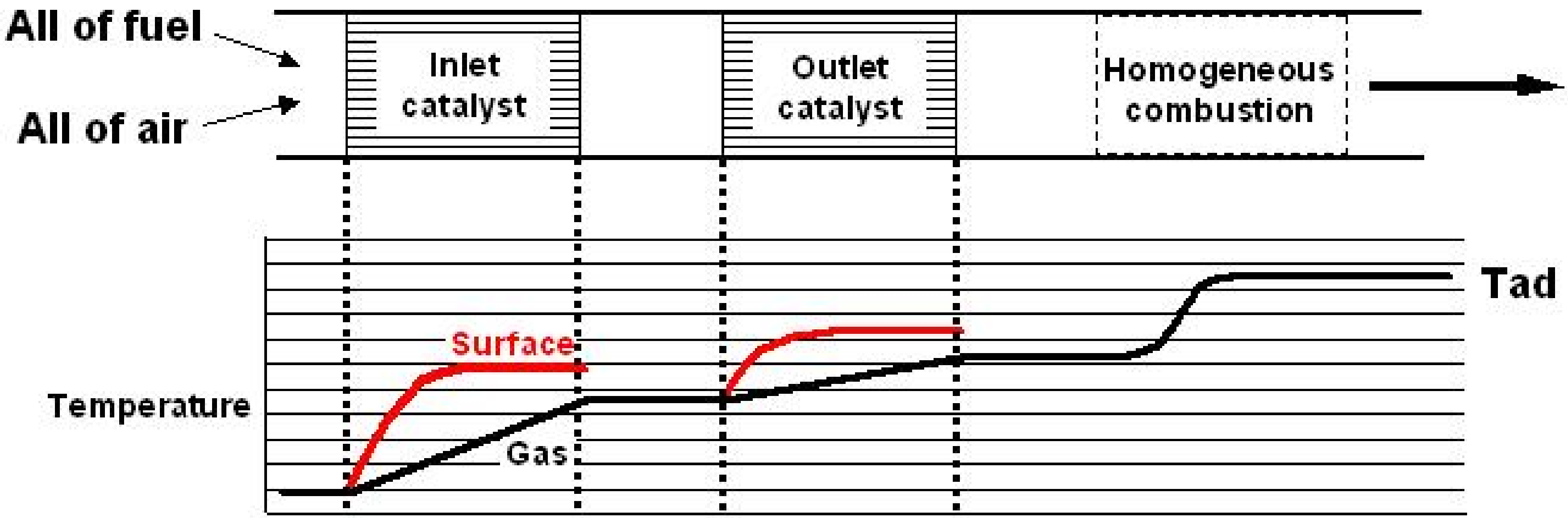
Catalytic Combustion System Traditional Approach



- Catalyst surface temp rapidly approaches 1300 °C
- At 1300 °C, damage to catalyst will occur
  - Noble metal vaporization
  - Loss of surface area

Catalytic Combustion System



- High activity
- Low lightoff T
- Designed for low wall T

- Higher wall T (design limits max wall T)
- High outlet gas T

Sufficient time to:
- Complete CH_4 combustion
- Complete UHC and CO burnout

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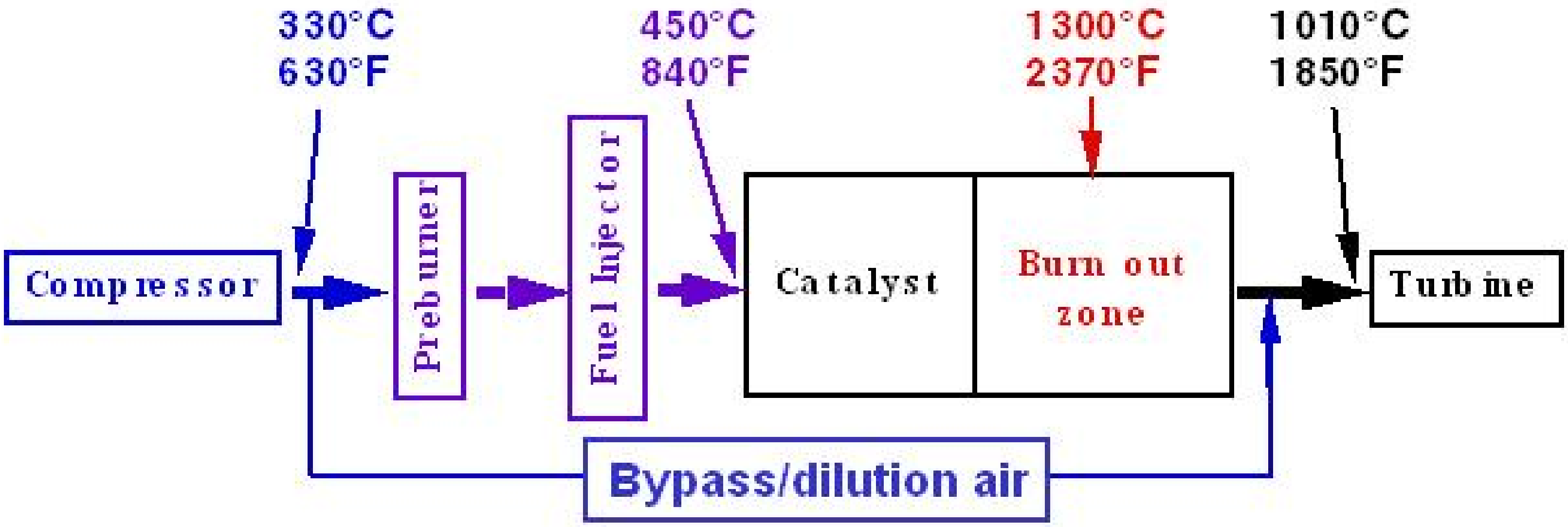
Catalytic Combustion System



- Preburner provides required catalyst inlet temperature
- Catalyst fuel injector produces a uniform fuel/air mixture for the catalyst
- High post catalyst temperature oxidizes CO to < 10 ppm
- Bypass and dilution air provides required turbine inlet temperature

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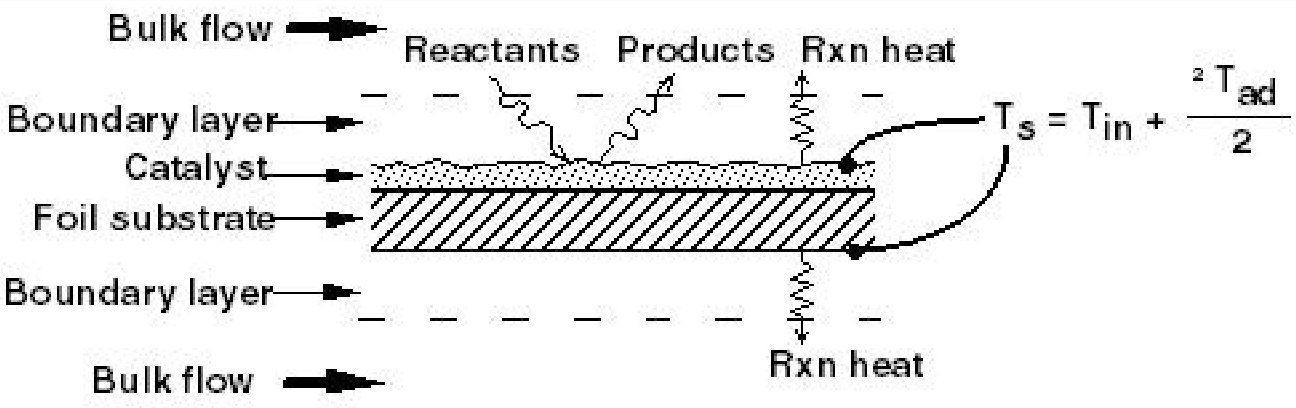
Catalytic Combustion System

Integral Heat Exchange Limits Catalyst Temp



- Solid cross-section essentially isothermal
- Equal heat transferred to catalyzed and non-catalyzed channels
- Maximum conversion = 50%
- Maximum wall temperature = $T_{in} + \frac{1}{2}{}^2 T_{ad}$
- Example: Inlet gas T = 700°C (1290°F)
  Tad = 1300°C (2370°F)

non-IHE wall T	=	1300°C(2370°F)
IHE wall T	=	1000°C (1830°F)

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Catalytic Combustion System

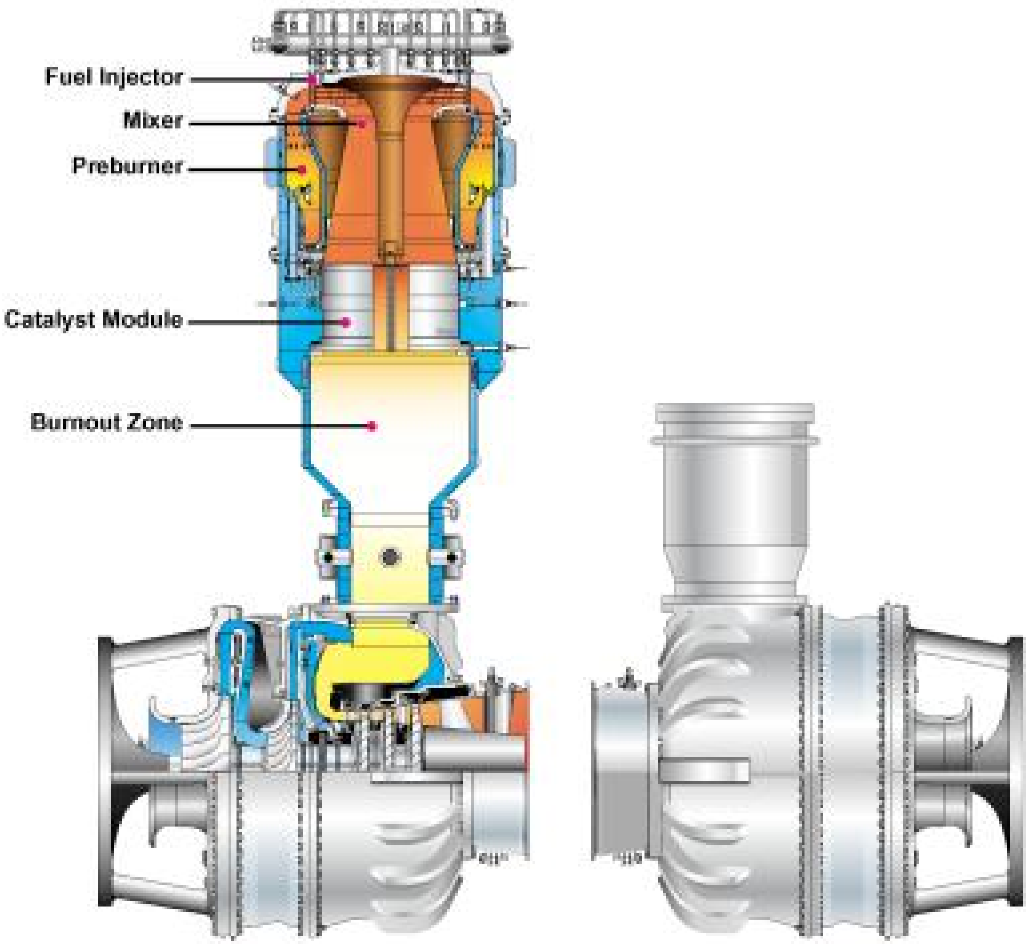
Catalyst designed to control its own temperature:

Active form

Inactive form

$$PdO \underset{\text{Low Temp}}{\overset{\text{High Temp}}{\rightleftharpoons}} Pd + \frac{1}{2} O_2$$

Catalytic Combustion System



Xonon® Configuration DLE Configuration

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- **Field Results**
  - Silicon Valley Power
  - Sonoma Development Center
- Summary

Field Results - Silicon Valley Power

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Field Results - Silicon Valley Power

RAMD: Reliability, Availability, Maintainability, Durability

Performance Criteria	Results
Operating Hours	> 14000
NOx emissions	< 2.5 ppm (corrected to 15% O_2)
CO emissions	< 6 ppm (corrected to 15% O_2)
VOC emissions	< 2 ppm
Reliability[1]	> 98%
Reliability[2]	> 99%

[1] Total turbine engine and catalytic combustor system reliability
[2] Catalytic combustion system reliability

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Field Results - Sonoma Development Center

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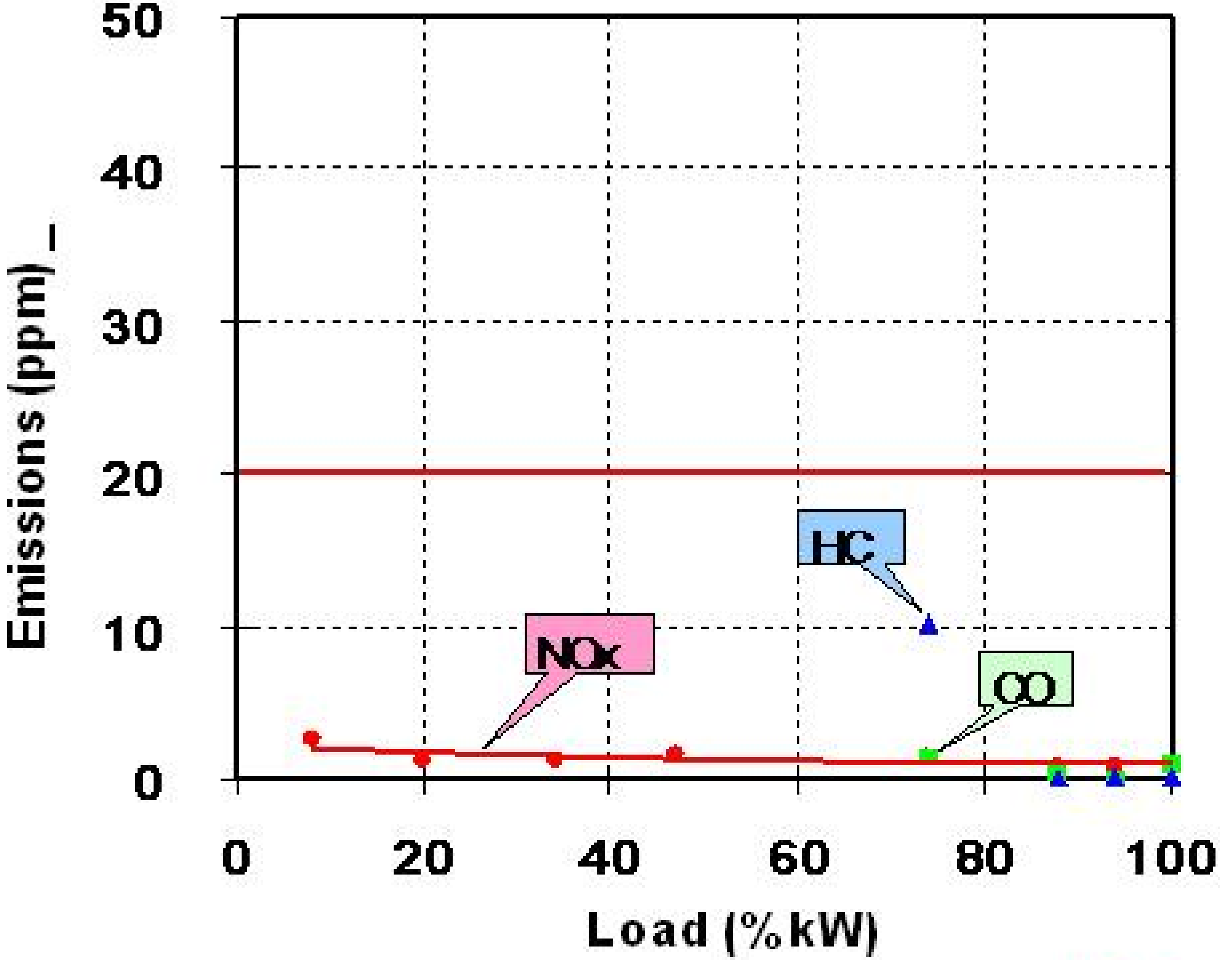
Field Results - Sonoma Development Center



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Field Results - Sonoma Development Center

"We're obviously within the legal limits as far as the BAAQMD is concerned and it reads down as far as it needs to. But we would like to be able to read it exactly so everybody can see what we're doing."

Mary Lavin, Environmental Specialist

Sonoma Development Center

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Field Results - Sonoma Development Center

"About the only problem is that we don't have another one sitting right next to it."

Ron Johnson, Chief Engineer

Sonoma Development Center

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Turbines With Catalytic Combustion

- No “Black Magic”
- Known Maintenance and Repair Requirements

VERY Low Exhaust Emissions

- Similar To Fuel Cells
- 70 - 100% Load

Completely Environmentally Friendly

- No SCR Required (No Ammonia Storage)
- No Oil Changes
- No Coolant Required

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Summary

How clean is clean???

- Industry Example
- Environmental Example

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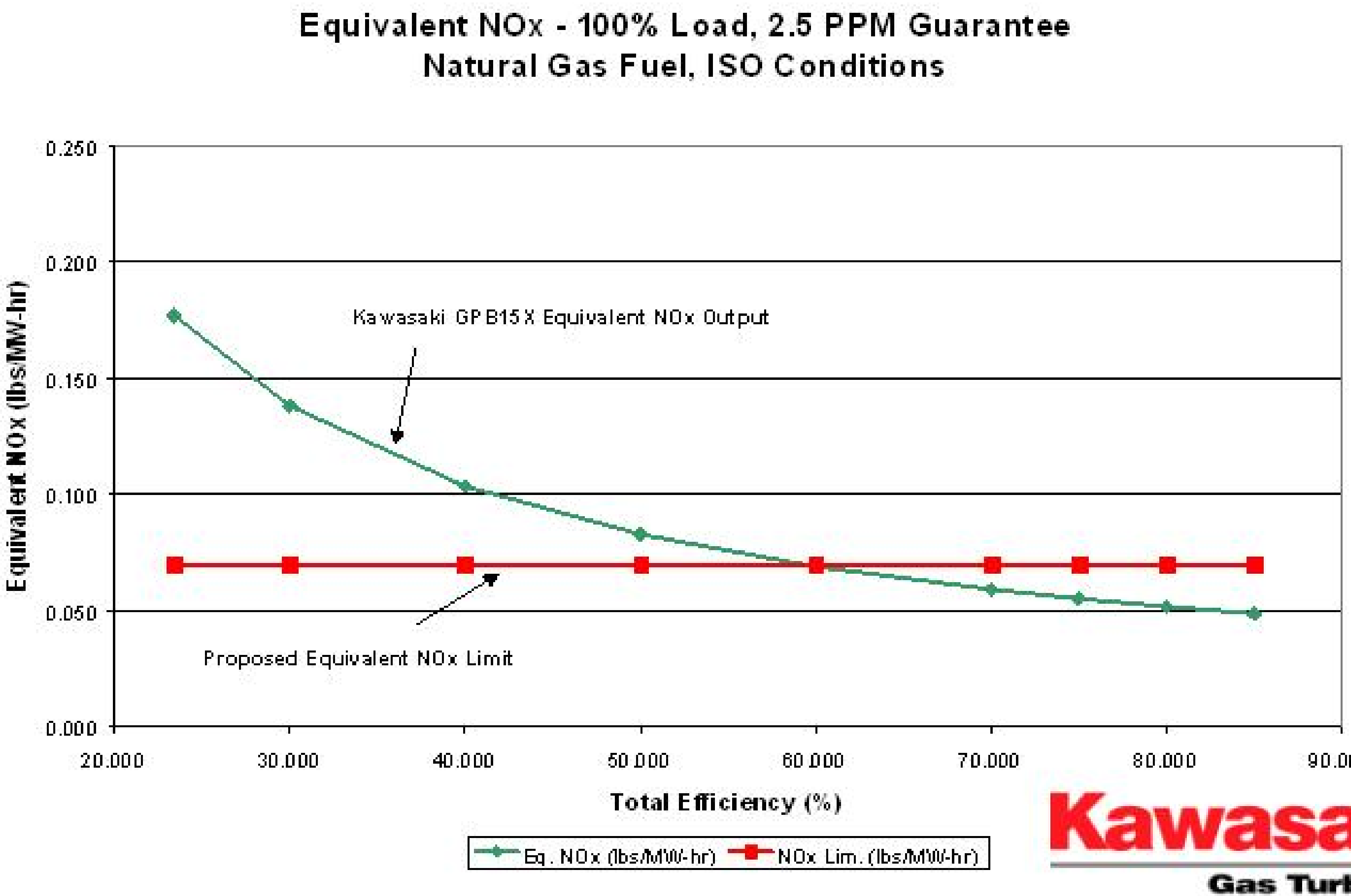
Summary



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Summary

Summary

A single lightning strike makes as much NOx in an instant as a Kawasaki Gas Turbine with catalytic combustion does in an entire year!!

Summary

- Catalytic Combustion Available
- Next Generation Of Combustion Technology
- Low Risk
- Cost Effective
- In Production

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